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INFRARED QUENCHING OF THE PHOTOVOLTAIC EFFECT IN CADMIUM SULFIDE

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ABSTRACT

Experimental investigation of the effect of IR radiation on the photovoltaic effect in cadmium sulfide excited by visible light (600 m μ region of the spectrum). It is shown that IR bias illumination can have both a stimulating and suppressing effect, depending on the intensity of the visible light. As distinct from photoconductivity, only one maximum of IR stimulation (or quenching) is observed for the photovoltaic effect; this maximum corresponds to a wavelength of 0.85μ.

The quenching effect of infrared (IR) light on the photoconductivity of cadmium sulfide has already been rather thoroughly studied. /45* Cadmium sulfide photoresistors which are insensitive in the infrared region of the spectrum decrease their sensitivity in the active region of the spectrum (500-700μ) under the effect of infrared radiation. The infrared quenching effect has been studied both in single crystals (Ref. 1) and in polycrystalline layers of cadmium sulfide (Ref. 2).

It was found that the IR quenching maximums correspond to 0.9 and 1.4μ. The quenching phenomenon does not, however, exhaust the effect of infrared radiation on the photoconductivity of CdS in the visible region of the spectrum. Serdyuk and Sera (Ref. 1) have shown that in the case of

* Note: Numbers in the margin indicate pagination in the original foreign text.

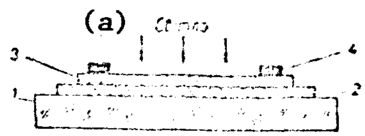


Figure 1

Diagrammatic Representation of CdS-Cu Photocell. (a) -- Light;

1-Glass coating; 2-Copper film;
3- Cadmium sulfide film; 4-Calcium aluminum electrode

cadmium sulf[illegible] the effect of IR stimulation can also be observed

which consists of an increase in the photocurrent excited by visible (green) light under the effect of IR radiation.

The influence of infrared radiation on the photovoltaic effect in cadmium sulfide has not been studied until the present. Woods and Champion (Ref. 3) alone have mentioned -- without explanations -- the substantial increase in short-circuit current excited by weak light (λ =700μ) in single-crystal CdS photocells when IR radiation is applied.

Maximum stimulation corresponds to λ =0.9μ. No second maximum (λ = 1.4μ) was detected. No study was made of infrared quenching of the photovoltaic effect. A study of IR quenching and stimulation of the photovoltaic effect makes it possible to establish the connection between this effect and the photoconductivity of cadmium sulfide. Comparison of the position and role of corresponding local levels in the forbidden zone in these two cases permits a more detailed analysis of the complex mechanism of photoelectric phenomena in this semiconductor, which is right now a moot question.

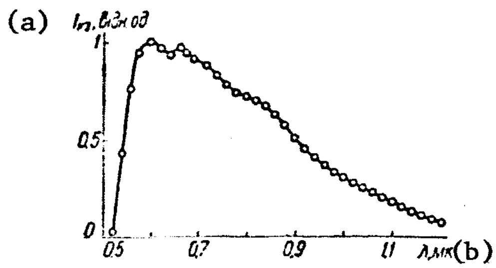


Figure 2

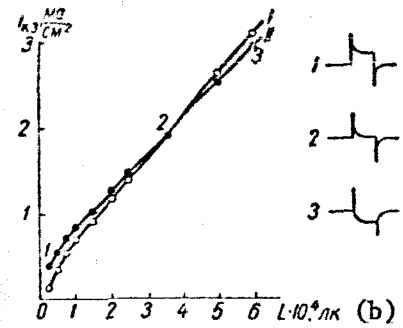
Spectral Distribution of Short-Circuit Current of CdS-Cu Photocell in Spectrum of Uniform Energy.

a -- I_{sc}, relative units; b -- λ, μ.

In our work we used polycrystalline film photocells on a CdS base which was obtained by thermal varopization of CdS powder under vacuum ($\sim 10^{-5}$ torr) onto a copper film (at a deposition temperature of 200°C). Figure 1 shows the photocell construction. Thickness of the CdS film was 2-5μ, specific resistance was 0.1-1 ohm·cm, active area of the photocell was 1-2 sq.cm. The source of light in the 0.4-2μ region was an incandescent bulb. A UM-2 monochromator or filters were employed to produce monochromatic light.

Figure 2 gives the spectral sensitivity curve (amount of short-circuit current per unit of incident light energy) of one of the cells. It is roughly similar to the curves obtained by other investigators /46
in the case of CdS-Cu film photocells. Here two sensitivity maxima are clearly visible at 600 and 660 mμ. The first of these maxima corresponds to the absorption boundary in polycrystalline cadmium sulfide; the second, perhaps, is caused by copper impurities in the CdS layer (Ref. 4). This figure also shows that the given photocell has a certain sensitivity in the near infrared region.

(a)



(b)

Figure 3

Lux-Ampere Characteristic of CdS-Cu Photocell Under Different Degrees of Illumination by Visible Light.

I -- Without IR radiation, II -- With IR radiation. On the right -- oscillogaams representing kinetics of IR stimulation and IR quenching processes.

a -- I_{sc}, ma/sq.cm; b-- $L \cdot 10^4$ lux

Nevertheless, as our measurements indicated, the total effect of the stimulating light from the 600 mμ region and of the infrared radiation from the 0.8-1.5μ region is not additive (the sum of the amounts of photocurrent excited by visible light and IR radiation, when measured separately, exceeds the photocurrent generated by simultaneous action of visible light and IR radiation) and depends on the intensity of the exciting light. Figure 3 gives two lux-ampere characteristics of the same photocell -- one derived without IR radiation and the other with IR radiation of constant intensity. It is evident that the stimulating action of IR radiation, which is clearly manifest in the low illumination region, gradually disappears as illumination increases, and is replaced by infrared quenching of the photovoltaic effect in the high illumination region.

The non-additivity of the exciting light and IR radiation action indicates that, in this case, an IR stimulating and an IR quenching effect take place at the same time. The proportion of each of these processes in the total effect is indicated by the intensity of the exciting light.

This result is, to a certain extent, similar to that obtained when studying IR quenching of the photoconductivity of single CdS crystals (Ref. 1).

One distinguishing feature of the photovoltaic effect is that IR radiation was found to be effective only from the 0.85μ spectral region. Light from the region with a maximum at λ = 1.4μ, however, has no effect on photocell operation.

The influence of IR radiation from the spectral region with a maximum at λ= 0.85μ on the CdS photovoltaic effect, as well as the very fact that sensitivity exists in this region of CdS photocells, may be explained by means of a model having double optical passages which was first proposed by Lashkarev and Fedorus (Ref. 5) to explain certain peculiarities in the photoconductivity of cadmium sulfide.

In fact, a stationary photoelectromotive force is known to be /47 possible when only non-equilibrium minority current carriers appear in a semiconductor (holes in the case of n-type CdS). Such carriers always appear in the fundamental absorption region when "electron-hole" pairs are excited because of the passage of electrons from the valence zone into the conductivity zone.

Non-equilibrium minority carriers may also appear in an impurity absorption region and a stationary photoelectromotive force may be created there (Ref. 6), for example, in the case of double optical passages -- optical passages of electrons from the impurity levels into the conductive zone with subsequent transfer of electrons from the valence zone onto these levels under the action of light from the same spectral region.

In the case of n-type semiconductors, non-equilibrium holes (minority carriers) are formed in the valence zone. If a p-n junction or contact with the metal is found very near these carriers (at a distance on the order of a diffusion length) the non-equilibrium holes, despite the short time of their existence in the cadmium sulfide, will be partially extracted by the barrier field from the region where they were generated and will participate in creating the photoelectromotive force. This may explain the stimulating action of IR radiation on the operation of CdS-photocells at low fundamental light intensities.

Along with the rise in visible light intensity, there is a growth in the cell's steady photoelectromotive force which compensates for the barrier field of the p-n junction (of the semiconductor-metal contact). Under these conditions the additional concentration of non-equilibrium minority carriers (holes), which occurs when IR radiation is turned on, no longer leads to an increase in the current across the junction, but merely helps strengthen the recombination of electron-hole pairs. In other words, the IR radiation has a quenching effect.

Within the limits of the mechanism described, the complex appearance of kinetic curves -- oscillograms may also be explained (Fig. 3), which depict the action of physically modulated IR radiation (pulse front rise time of $\sim 10^{-5}$ sec) on the current generated by a CdS photocell under different intensities of visible (unmodulated) light. Sharp bursts which appear when the IR radiation is turned on and off are apparently connected with the lesser time lag, determined by hole flight-time across the p-n junction, in the IR stimulation process as compared to IR quenching, whose time lag is determined by the constant time taken by electrons and holes to recombine. The steady pulse level in the oscillograms corresponds to the resulting equilibrium photocurrent of the cell, which is reached because of the uniform action of the stimulating and quenching effect of IR radiation. Because of the strengthened quenching action of IR light, this level during the transition from weak visible light intensities to strong intensities is shifted below the signal output level which corresponds to visible light alone. If the stimulating and quenching effects are equal (point 2 in Fig. 3), then splashes are seen above the output level only at the instants when the IR radiation is turned on and off (curve 2, Fig. 3).

With a model of double optical passages, it is also easy to explain the absence of another IR stimulation (or IR quenching) maximum at $\lambda = 1.4\mu$. In fact, double optical passage obviously is possible only when the energy of light quanta is not less than half the width of the forbidden zone of the semiconductor. Hence it is clear why light from the 1.4μ region ($h\nu \simeq 0.9$ ev) cannot influence the photovoltaic effect, for the forbidden zone width in CdS is 2.4 ev. Nevertheless its effect on photoconductivity is not excluded here. It should be noted that the lack of quenching at $\lambda = 1.4\mu$ in our case is possibly also caused by the absence of internodular sulfur atoms in the CdS films obtained by vacuum vaporization (Refs. 7, 8).

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